Immune algorithm

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Pick To: This article analyzes the advantages and disadvantages of standard genetic algorithms, Drawing on the concepts and theories of immunity in life sciences, a new algorithm is proposed ——— Immune algorithm. The core of the algorithm lies in the construction of immune operators, The immune operator is completed through two steps: vaccination and immune selection. The theory proves that the immune algorithm is convergent and combined TSP problem, The selection of immune vaccine and the construction method of immune operator are proposed. Finally, the immune algorithm is used to 75 Urban TSP The problem was simulated and calculated, The calculation process is compared with the standard genetic algorithm. The results show that the algorithm has a significant effect on reducing the fluctuation phenomenon of the genetic algorithm in the later period. At the same time, the speed of convergence is greatly improved.

Key words: Immune algorithm; antibody; convergence; TSP problem

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The Immune Algorithm

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Abstract: Based on analyses of GA ′ s properties, a novel algorithm, the immune algorithm — IA, is proposed with analogies to the concept and the theory of immunity in biotic science. The core of the algorithm lies on constructing the immune operator that is realized by vaccination and immune selection.IA is approved theoretically convergent.The strategies and the methods of selecting and constructing a vaccine for TSP are given in this paper.A simulation test of 75-city TSP is done with IA, and its computational process is compared with that of canonical genetic algorithms.The results show that IA can evidently alleviate the undulate phenomenon at the end of the evolutionary process, Therefore increases the convergent speed.

Key words: the immune algorithm; antibody; convergence; TSP

1 introduction

In the field of life sciences, People already have a genetic (Heredity) With immunity (Immunity) And other natural phenomena have been extensively and deeply studied. Bagley with Rosenberg On the basis of analyzing and understanding these research results, Draw on its relevant content and knowledge, Especially the theories and concepts in genetics, And successfully applied it to some fields of engineering science, and received good results [1, 2]. From the mid-1980s, the United States Michigan University's Holland The professor not only summarized and promoted the genetic concepts proposed by previous scholars, And gives a concise , Clear algorithm description, And thus form the current general sense " Genetic algorithm "(Genetic Algorithm — GA) [3]. Because genetic algorithms are more convenient to use than traditional search algorithms in the past , Robust , Facilitates parallel processing and other features, Therefore, it is widely used in combinatorial optimization [4, 5] , Structural design [6] , artificial intelligence[7] Other fields. On the other hand, Farmer with Bersini Waiting for others in different periods , The concept of immunity is involved to varying degrees [8, 9].

As we all know, Genetic algorithm is a kind of " Generate + Detect "(generateand-test) Search algorithm for the iterative process [10]. Theoretically, during the iterative process, On the premise of retaining the best individuals of the previous generation, Genetic algorithm is globally convergent [11]. however, During the implementation of the algorithm, it is not difficult to find two main inheritance The operators are all randomly under the condition of a certain probability of occurrence , Iterative search without guidance, Therefore, while providing evolutionary opportunities for individuals in the group, they also inevitably have the possibility of degradation. In some cases, this degradation phenomenon is quite obvious. On the other hand, Each actual problem to be asked will have its own basic , Obvious feature information or knowledge. However, the crossover and mutation operators of the genetic algorithm are relatively fixed. When solving the problem, the variable flexibility is less. This is undoubtedly beneficial to the generality of the algorithm, but it ignores the problem The auxiliary role of feature information in solving problems, Especially when solving some complex problems, this kind of " Neglect " The losses caused are often more obvious.

Practice also shows that Only use genetic algorithms or evolutionary algorithms represented by them, It is far from being able to imitate human intelligence's ability to process things, and it is necessary to dig and use human intelligence resources in a deeper level. From this point, learn biointelligence, development, Furthermore, the use of biological intelligence is an eternal topic of evolutionary algorithms and even intelligent computing. The author strives to introduce the concept of immunity in life science into the field of engineering practice, With the help of relevant knowledge and theories and organically combining them with some existing intelligent algorithms to establish new evolutionary theories and algorithms, To improve the overall performance of the algorithm. Based on this idea, this article applies the concept of immunity and its theory to genetic algorithms, While retaining the excellent characteristics of the original algorithm

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Under the premise, Try to have a choice , Purposefully use some feature information or knowledge in the question to be suppressed to suppress the degradation phenomenon that occurs in its optimization process.This algorithm is called the immune algorithm Immune Algorithm — IA). This article gives the specific steps of the algorithm, Proved its global convergence, The selection strategy of immune vaccine and the construction method of immune operator are proposed, Theoretical analysis TSP The simulation results of the problem show that the immune algorithm is not only effective but also feasible, And it solves the degradation problem in genetic algorithm well.

2 Immune algorithm and its convergence

2.1 Immune algorithm

The concept of immunity in this article was inspired by the biological sciences [12]. In the specific implementation process, This paper introduces a new operator based on the framework of the original standard genetic algorithm, Immune operator Immune Operator). Similar to the immune theory in life sciences, There are also two types of immune operators: full immunity (Full Immunity) And target immunity (Target Immunity), The two correspond to non-specific immunity and specific immunity in life science. Full immunity means that each individual in the group after the role of genetic operators, The type of immunization that performs an immunization operation for each link; target immunization refers to the genetic operation, after a certain judgment, A type of immune reaction occurs only at the point of action. The former is mainly used in the initial stage of individual evolution, And in the evolution process, basically no effect, Otherwise it will most likely produce what is said in the usual sense " Assimilation "(Assimilative Phenomenon); The latter will generally accompany the entire process of group evolution, It is a basic operator of immune operations.

During the actual operation, First of all, the problem solved (here regarded as antigen, Antigen) Conduct specific analysis, The most basic feature information extracted from it (The vaccine, Vaccine); Secondly, This feature information is processed to transform it into a solution to the problem (the collection of various solutions obtained according to this solution is collectively referred to as the antibody produced based on the above vaccine, Antibody); Finally, this program is converted into an immune operator in an appropriate form to implement specific operations. What needs to be explained here is that There is often more than one feature information of the question to be asked, that is, there may be more than one vaccine that can be extracted for a specific antigen, then during the vaccination process, a vaccine can be randomly selected for injection, or you can use Multiple vaccines are combined according to a certain logical relationship before being injected. Some issues that should be noted about the selection of vaccines will be described in the following section. 3.3 The section discusses in detail in the form of examples.

In summary, The immunization idea proposed in this article is mainly based on the reasonable extraction of vaccines. It is done through two steps of vaccination and immunization selection. The former is to improve adaptability, The latter is to prevent the degradation of the group. Its doors are:

Vaccination: set individual x, Vaccination refers to modification according to prior knowledge x Genes at certain loci, The resulting individual has a higher degree of fitness with a higher probability. First consider the following two special cases: First, if the individual y The information at each locus is wrong, That is, each code is different from the best individual, For any individual x, x Transfer to y The probability is 0; Second, if the individual x Is correct for each locus, ie x Already the best individual, then x By probability 1 Transfer to x. In addition, With groups $c = (x_1, x_2, \ldots, x_{n0})$, Correct c Vaccination means c In proportion α Random selection $n_\alpha = \alpha n$ ($0 < \alpha \leq 1$) Individual operations. The vaccine is extracted from the prior knowledge of the problem, The amount of information it contains and its accuracy emphasize the performance of the algorithm Important role.

Immune selection: This operation is completed in two steps. The first step is immunoassay, which is to detect individuals who have been vaccinated, If the fitness is still not as good as the parent, it means that , Severe degradation occurs in the process of mutation. At this time, the individual will be replaced by the corresponding individual in the parent; if the fitness of the offspring is better than that of the parent, the second step is processed. The second step is annealing selection [13]. In the current offspring group $E_k = (x_1, \ldots, x_{n0})$ China-Israel probability:

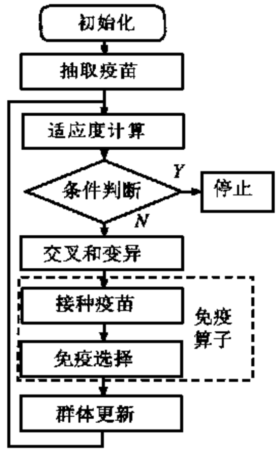

Fig 1 Flow chart of immune algorithm

$$P(x_i) = e^{f(x_i)/T_k} / \sum_{i=1}^{n0} e^{f(x_i)/T_k} \tag{1}$$

Select individual x_i Enter a new parent group, of which $f(x_i)$ For the individual x_i Adaptability, $\{T_k\}$ Is approaching 0 Temper control sequence.

algorithm 1: Immune algorithm IA)

① Randomly generate initial parent population A_1; ② Extract vaccines based on prior knowledge; ③ If the current group contains the best individuals, Then the algorithm stops running and outputs the result; otherwise it continues; ④ For the current section k Surrogate parent population A_k Perform crossover operations to get the population B_k; ⑤ Correct B_k Perform mutation operation to get the population C_k; ⑥ Correct C_k Perform the vaccination operation to get the population D_k; ⑦ Correct D_k Perform immune selection operation to get a new generation of male parents A_{k+1}, Go to ③.

The running process of the algorithm can be compared with the figure 1 Related links, the specific content of the immunization operation will be 3.2 Section gives a detailed discussion.

2.2 Convergence of immune algorithm

Let the size of the first generation population be n_0, Then the size of all populations are n_0, All individuals in the population are l Bitwise q Binary coding. The crossover operation in the algorithm can choose one or more points. The mutation operation is based on the probability of each gene. P_M Mutation independently of each other, The probability of being in any other state after mutation is $1/q-1$. The state transition of the algorithm can be expressed by the following random process:

$$A_k \xrightarrow{\text{cross}} B_k \xrightarrow{\text{Mutations}} C_k \xrightarrow{\text{vaccination}} D_k \xrightarrow{\text{Immune selection}} A_{k+1}$$

Among them A_k To D_k State transitions constitute a Markov chain, and A_{k+1} The state of is related to the state of the preceding variables. But the random process $\{A_k\ k = 1, 2, \ldots\}$ Obviously it is still a Markov process. X For the search space, that is, the space of all individuals, the scale will be n_0 Group of people think of as state space $S = X^{n0}$ A point in, Each coordinate is X Individuals in. S Express S Number of states in $s_i \in S$, $i = 1, 2, \ldots,$ S , Express s_i Yes S One of State s_i s_j Express s_i, s_j As X Contains a subset of. V_{ik} Represents a random variable V In section k State of being s_i. Assume f Yes X Fitness function on, let

$$S^* = \{x \in X \mid f(x) = \max_{x_i \in X} f(x_i)\} \tag{2}$$

Then the convergence of the algorithm can be defined as follows.

definition 1 If for any initial distribution

$$\lim_{k \to \infty} \sum_{s_i \cap S^* \neq \emptyset} P\{A_{ik}\} = 1 \tag{3}$$

It is called algorithm convergence.

The definition shows that: algorithm convergence means that when the algorithm iterates to a sufficient number of times, The probability that the group contains the global best individual is close to 1. This definition is the so-called probability 1 convergence.

theorem 1 Immune algorithm is probability 1 Convergent. The proof process of the theorem is omitted. However, One thing to note here is that if the immune operator is omitted from the immune algorithm, It can be proved that the algorithm will no longer guarantee convergence to the global optimal value [11], Or it is strongly non-convergent [13].

3 The mechanism and structure of immune operator

3.1 Mechanism of immune operator

Such as 2.1 As mentioned in the section, The immune operator is composed of two parts: vaccination and immune selection. Among them, the vaccine refers to more or less prior knowledge based on people's treatment problems. A basic characteristic information extracted from it; antibody refers to a type of solution derived from this characteristic information. The former can be regarded as a matching pattern that the best individual to be sought (Schema) An estimate of the latter; the latter is a sample formed by matching this pattern. 1 It is not difficult to find in the description of The correct selection of vaccines is very important to the efficiency of the algorithm. It is the same as the coding in the general genetic algorithm, which is the basis and guarantee for the effective operation of the immune operation. But what needs to be explained is: the quality of the selected vaccine, The quality of antibody production, It will only seriously affect the function of vaccination in the immunization operator, It does not involve the convergence of the algorithm. Because the convergence of the immune algorithm is ultimately guaranteed by the immune selection in the immune operator, let's examine the role of immune selection in the operation of the algorithm.

theorem 2 Under the effect of immune selection, If the vaccine improves antibody fitness, And higher than the average fitness of the current group, Then the pattern corresponding to the vaccine will spread exponentially in the group; otherwise, It will be contained or decayed exponentially.

Reference to the proof of the model theorem in the genetic algorithm can verify the correctness of the above theorem. And from the above theorem, it can be seen that the positive role of immune selection in strengthening vaccination Robust in eliminating its negative effects.

The application object of the immune algorithm is mainly for some problems that increase rapidly with the scale, such as NP Problems, etc. The characteristic of such problems is that when the scale is small, The problem is generally easy to solve or it is easy to find the solution rule under its local conditions. When selecting a vaccine for this type of problem (can be generalized to a general problem), you can make an immune vaccine based on the characteristic information of the problem Or on the basis of specific analysis, Consider reducing the scale of the original problem, Add some local conditions to simplify the problem. This simplified problem-solving law can be used as a way to select vaccines. However, in the actual selection process, It should be considered that on the one hand, the more thorough the localization of the original problem, The solution rule under local conditions is more obvious, although it is easy to obtain vaccines at this time, But the amount of calculations to find all such vaccines will increase significantly; on the other hand, Each vaccine uses some local information to find the global optimal solution. That is to estimate the mode of the solution on a certain component, Therefore, there is no need to be accurate for each vaccine. Therefore, according to the specific situation of localization of the original problem, Select some current iterative optimization algorithms to extract vaccines.

3.2 Immune operator execution algorithm

For convenience of expression, First, explain some of the special symbols that will be used below. $a_{iH,k}$ For the first k Daidi i Individuals a_{ik} After vaccination Of antibodies, P_I The probability of vaccinating an individual, P_V To update the probability of the vaccine, $V(a_{ik}, h_j)$ Expression by mode h_j Modify individual a_{ik} Vaccination operations on the gene, n with m The size of the population and the vaccine respectively. Then, the process of constructing and applying the immune operator for a certain problem is as follows:

algorithm 2: Immune operator execution algorithm

Begin:

Vaccination:

Analyze the questions to be asked and collect characteristic information;

Estimate patterns at specific loci based on feature information: $H = \{h_j \mid j = 1, 2, \ldots, m\}$; k = 0 and j = 0;

while (Conditions = True)

if $\{P_V\}$ = True, then j = j + 1;

i = 0;

for (i ≤ n)

vaccination: $a_{iH,k} = V\{P_I\}\{a_{ik}, h_j\}$;

Immunoassay: if $a_{iH,k} < a_{ik-1}$, then $a_{ik} = a_{ik-1}$;

else $a_{ik} = a_{iH,k}$;

i = i + 1;

Annealing options: $A_{k+1} = S(A_k)$;

k = k + 1; End

The shutdown conditions in the above algorithm can use the maximum number of iterations method or the maximum number of times method of counting the individual's best fitness continuously.

3.3 Selection example of immunization vaccine

First 3.1 The section briefly describes the general selection strategy of immune vaccines in the algorithm, and then combines TSP problem, Discuss the specific processes and steps.

(1) Analyze the question to be asked, and collect characteristic information. Assume that at a certain moment, someone starts from a city and wants to go to the next target city. In general, The first choice he considers is the city closest to the local distance. If the target city is exactly a city that has traveled before, the next target to be reached is replaced by the city with the smallest distance other than the city, and And so on. Although this method can not be used as a solution to the global problem, but in a very small range, such as only three , The situation in the four cities (relative to the overall problem, (This is a local problem), this consideration is often a better strategy. Of course, Whether it can be used as the final solution requires further judgment.

(2) Based on the above knowledge, the preparation of immune vaccines based on characteristic information TSP In terms of the characteristics of the problem, in the final solution, In the selection of the best path, It must include and to a large extent include the shortest distance between adjacent cities. TSP This feature of the problem can be used as a kind of feature information or knowledge for reference when solving the problem, so it can be regarded as a way to extract vaccines from the problem. So in the specific implementation process, only the general cycle Iterative methods can be used to find the neighboring cities of all cities (of course, a city may be adjacent to two or more cities, or it may not be). The vaccine is not an individual, Therefore, it cannot be used as a solution to the problem (as shown in the figure 4 (a) (The situation shown). It only has the characteristics of the individual at certain loci.

(3) Vaccination without loss of generality, design TSP All in question and the city A_i The nearest city

City for A_j. And the two are not directly connected but are in two sections of a certain path: A_{i-1} — A_i — A_{i+1} with A_{j-1} — A_j — A_{j+1}. As shown 2 The solid line shows. The current traversal path is: $\pi = \{A_0, \ldots, A_{i-1}, A_i, A_{i+1}, \ldots, A_{j-1}, A_j, A_{j+1}, \ldots, A_N\}$. The corresponding path length is:

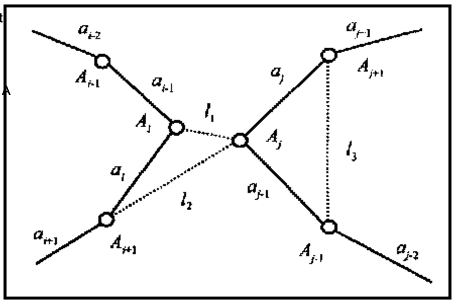

Fig 2 TSP Schematic diagram of the mechanism of the problem vaccine

$$D_\pi = \sum_{k=1}^{i-1} a_k + a_i + \sum_{k=i+1}^{j-2} a_k + a_{j-1} + a_j + \sum_{k=j+1}^{N} a_k \quad (4)$$

Probability of immunity P_i Under the conditions of occurrence, the city A_i In terms of, the immune operator will treat its neighboring cities A_j Ranked as its next target city, The original traversal path is adjusted to:

$\pi_c = \{A_0, \ldots, A_{i-1}, A_i, A_j, A_{i+1}, \ldots, A_{j-1}, A_{j+1}, \ldots, A_N\}$,

Then the corresponding path length change is:

$$D_{\pi c} = \sum_{k=1}^{i-1} a_k + l_1 + l_2 + \sum_{k=i+1}^{j-2} a_k + l_3 + \sum_{k=j+1}^{N} a_k \quad (5)$$

Comparative (4) Japanese (5), because A_j Is in all cities (that is, in the overall situation) and cities A_i The closest point, In A_i — A_j — A_{i+1} In the triangle formed l_1 Must be the shortest side or the second shortest side (in this case l_2 It must be the shortest side. Because if $a_i < l_1$, Then with A_i The nearest city is A_{i+1} Not A_j). While in A_{j-1}, A_j with A_{j+1} However, it is not necessarily of this nature. So in most cases, l_3 Compare $a_{j-1} + a_j$ The reduction is greater than $l_1 + l_2$ Compare a_i The amount of increase. And more importantly, in this local environment, The operator made an optimal adjustment to the path. Of course, whether this adjustment can contribute to the entire path, There is still further judgment to be made on the selection mechanism. However, From the analysis process, It is not difficult to derive the following relationship:

$$P(D_{\pi c} < D_\pi) P(D_{\pi c} > D_\pi) \quad (6)$$

In the formula, P (A) Representing an event A The probability of occurrence. " Adjustment " process, Yes TSP The problem-solving process is based on the immunization process of a specific vaccine.

4 TSP Immune algorithm for problems

TSP The problem is difficult to solve with conventional algorithms , typical NP Problem. In recent years, Solve with evolutionary calculations based on genetic algorithms TSP The problem has many results [4, 5]. To a certain extent, it is also indirectly used as an evaluation standard for various nonlinear optimization methods. TSP The problem is essentially n Coordinates (assumed n Location of a city) under certain conditions (limits of interconnected paths between cities), Find an integer arrangement that meets the following conditions $\pi = \{p_1, p_2, \ldots, p_n\}$ (one of them p_i Represents the best path i Number of cities):

$$D_\pi = \sum_{i=1}^{n-1} d(p_i, p_{i+1}) + d(p_n, p_1) = \lim \sum^{n} \left(\sum_{\substack{i,j=1 \\ i \neq j}} d(p_i, p_j) \right) \quad (7)$$

In the formula d (A, B) Indicates that the number is A with B The distance between the two cities.

4.1 Coding and fitness functions

For convenience and intuitiveness, this article uses n The order of visits in each city is TSP The coding of the problem. The fitness function is calculated using the following formula:

$$f(\pi_i) = (76.5 \times L \times N) / D_{\pi i} \sqrt{\ } \quad (8)$$

among them L Is the side length of the smallest square containing all cities, N Is the number of cities, $D_{\pi i}$ For the actual arrangement π_i Under the path length.

4.2 Crossover and mutation operators

For the design of cross operation, In principle, two-point intersection is adopted, where the position of the intersection point is randomly determined (so there may be a point of intersection in the actual operation process); in terms of mutation operation, The algorithm adds links to inheritance of genetic individual genotype characteristics and evaluation of the diversity of individual characteristics required for further optimization. On this basis, a partial path variation method is designed. This method selects a section of the full-length path The starting and ending points of the path sub-segments are estimated and determined by the evaluation results. The specific operation is to use continuous n Replacement method, of which n Genetic algebra K Decide, the specific relationship is as follows:

$$n = [N / M + \exp(-\alpha K)] \quad (9)$$

among them N Is the number of cities; M Is the number of path subsections; α Is a constant, means n Follow K The speed of change.

4.3 Immune operator

Such as 2.1 As mentioned in the section, There are two types of immune operators, namely full immunity and target immunity, The specific question should be based on the nature of the vaccine that can be extracted to decide which immunization procedure to use. TSP problem, Because it is extremely difficult to find a vaccine that is suitable for the entire antigen (ie, global problem solving), the target immunity is used in the simulation experiment. Specifically, before solving the problem, first select from the points around each city A point closest to the distance or path is used as the vaccine injected during the target immunization operation on the city point during the execution of the algorithm. After each genetic operation, Randomly select some individuals for injection (as shown in section 3), Then perform immunoassay, That is, testing the vaccinated individuals: if the fitness is improved, continue; otherwise, If the fitness is still not as good as the parent, it means that , During the process of mutation, serious degradation has occurred. At this time, the individual will be replaced by the corresponding individual in the parent. In the selection stage, the individual of the offspring is represented by the formula (1)

Calculate the probability of being selected and make corresponding condition judgment.

In the simulation experiment, the famous 75 Urban TSP Take the problem as an example, and take the group size as 100; Crossover probability 0.5 ~ 0.85, Probability of variation 0.2 ~ 0.01, The probability of an individual being vaccinated 0.2 ~ 0.3, Probability of updating vaccine 0.5 ~ 0.8 Between the changes with the evolution process; in addition M with α Were taken as 10 with 0.04, Annealing temperature in annealing selection T Calculate as follows:

$$T_k = \ln((T_0 / k) + 1), T_0 = 100 \quad (10)$$

among them k It is an evolutionary algebra. Under the premise that the basic parameters remain unchanged, the general genetic algorithm and immune algorithm are applied to TSP Solve the problem. If it is assumed that the best fitness value of the group is 100 If it is not updated during successive iterations, then the individual corresponding to the best fitness value is considered to be the best individual. 10 Record an evolutionary result on the next generation, then the immune algorithm 940 The first generation appeared the best individual that was later identified, The general genetic algorithm is 3550 The best individual appears only in the new generation. In order to more clearly indicate the overall evolution of the group in the two algorithms, The comparison of the changes in the best fitness value and the corresponding average fitness value of their offspring populations with the evolution process are plotted in the figure 3, The vaccine selected in the calculation process and the final optimization path are shown in the figure 4 As shown. 3 Can also be seen in the latter to improve the search efficiency of the algorithm and eliminate the standard

The genetic algorithm's late oscillation phenomenon has obvious effects, And to a large extent, it accelerates the convergence speed of the original algorithm.

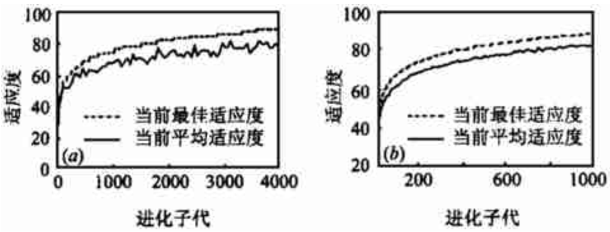

Fig 3 The curve of the fitness value of offspring with the evolution process (a) General Genetic algorithm calculation curve, (b) Immune algorithm calculation curve

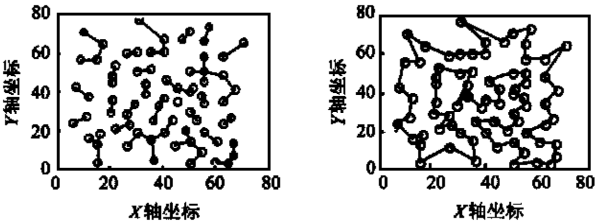

Fig 4 75 Urban TSP Schematic diagram of problem immune optimization simulation (a) Immunization vaccine, (b) Optimization path

5 conclusion and discussion

This paper proposes a new global parallel algorithm that combines immune mechanism and evolution mechanism ——— Immune algorithm, The global convergence is proved, the selection strategy of immune vaccine and the construction method of immune operator are given. Theoretical analysis and application TSP The experimental results of the question show that Compared with general genetic algorithm, immune algorithm is not only effective, Is also feasible, And it solves the degradation phenomenon in existing algorithms well, And the convergence speed has been significantly improved. Similar results have not been reported at home and abroad.

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